

Modeling of mechanical energy harvesting system by utilizing the weight of vehicle as a source of electrical energy for the portal gate system

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Abstract. The gate into residential or vehicle parking area is often equipped with a portal (barrier gate) that is a simple crossbar to block the road. Whenever a vehicle passes through the road, the portal is opened and closed by rotating mechanism of the portal at one end. Portals in public area, are usually not manually operated by officers, but automatic systems powered by an electric motor and become an integral unit with an electric parking ticket printer. In one operating cycle this unit requires small amount of electricity. However for repeatedly large numbers of operating cycle, the accumulation of required energy will also be large.

This study is modeling of a mechanical energy harvesting system utilizes the weight of a vehicle as a source of electrical energy. As the vehicle pass on energy harvesting system, electrical energy is produced to operate the automatic portal unit. Data taken from the specification of a light weight passenger vehicle provides net energi of 592 Nm to the mechanical energy harvesting system. It is more than enough as a source of energy to operate portal (barrier gate) for one operation cycle. The portal needs an energy of 221 Nm for every operation cycle.

Keywords: Mechanical energy harvesting system, portal gate system, vehicle's weight.

1. Introduction.

The mechanical energy harvesting system presented in this paper, is one in which the impulsive force of the vehicle's weight is converted into flywheel kinetic energy which is then used to drive the electric generator. The generated electricity will be stored in the battery as a storage of electrical energy for the portal driver motor and parking ticket printer. Energy harvesting system from running vehicles become an alternative energy harvesting system to obtain an electric energy [1]. In this kind of energy harvesting system, the electrical energy obtain from the mechanical motion can be stored on battery. The electrical energy stored on battery can be used even after the vehicle pass the mechanical energy harvesting system.

Flywheel kinetic energy stored in rotating flywheel can be used to rotate an electric generator. The use of flywheel as a device to convert translational movement to a rotary motion is common in mechanical system [2]. The design of the mechanical energy harvesting system is simple and easy to implement compare with more advanced energy harvesting system using piezoelectric power generation [3], [4]

and bistable system [5].

2. Theoretical background

The design of mechanical energy harvesting system presented in this paper consist of two sub system, i.e. mechanical system and electrical system. The mechanical system convert the weight of the vehicle as a source of energy to rotate the flywheel. The electrical system uses the flywheel rotation to drive the electric generator to generates electricity. The mechanical energy harvesting system is appropriate as a source of electrical energy for automatic portal (barrier gate) for shopping malls, business center and also residential area [6], [7], [8].

2.1 Mechanical system.

The schematic design of mechanical system for the mechanical energy harvesting system is shown in Fig. 1. Slider or sliding bump move downward when the wheel of vehicle pass over it. This translational motion of the slider will be convert into rotaional motion of flywheel using rack and pinion as shown in Fig. 2.

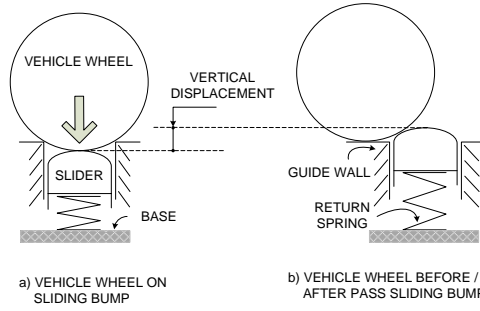


Figure 1. Design of the mechanical system.

The amount of energy obtained from the weight of the vehicle is stated in equation (1).

$$U_k = m_k g s_k \quad (1)$$

m_k is mass of the vehicle, g is acceleration of gravity and s_k is vertical displacement of the sliding bump.

To convert the energy obtained from the weight of the

vehicle to an electrical energy, the system is equipped with a mechanical system to rotate the flywheel. The shaft of the flywheel is connected to an electric generator. The system to convert translational movement into rotational motion of the mechanical energy harvesting system is shown in Fig. 2.

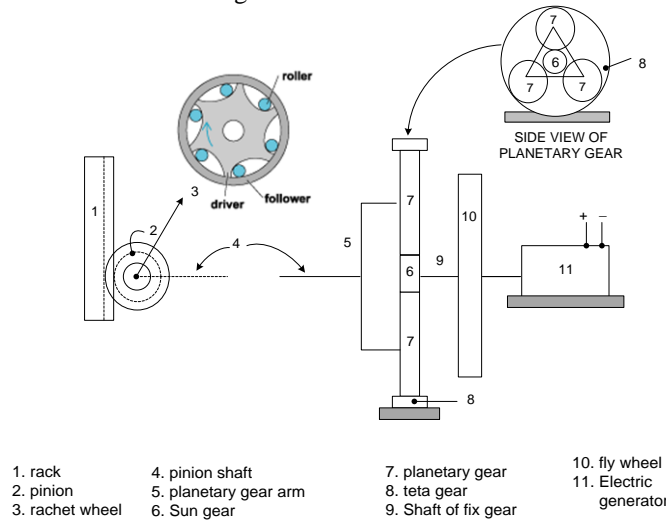


Figure 2. The system for converting translational into rotational motion.

As the vehicle pass the mechanical energy harvesting system, the wheel of the vehicle (see Fig. 1) will push the sliding bump down. The sliding bump that is connected to rack (1) and pinion (2) as shown in Fig. 2 will also rotate the flywheel which is connected to the shaft of the electric generator. The kinetic energy of the flywheel is expressed in equation (2).

$$E_f = \frac{1}{2} I \omega_f^2 \quad (2)$$

I is the mass moment of inertia of the flywheel and ω_f is the angular velocity of the flywheel. The kinematic relationship between vertical displacement of the rack (1) and rotational (angular) displacement of the pinion (2) is stated in equation (3).

$$s = r \theta \quad (3)$$

r is radius of pinion, s is vertical displacement of the rack and θ is rotational displacement of the pinion. If

the vertical displacement of the rack, $s = 12$ cm (for each time the vehicle wheel push the sliding bump down) and the pinion diameter is 6 cm, based on equation (3) the rotational or angular displacement of the pinion can be calculated using equation (4).

$$\theta = \frac{12}{3} \times 57,3^0 = 229,2^0 \quad (4)$$

If time for the vertical displacement of the rack ($s = 12$ cm) is designed for 0.2 sec, then angular velocity of the pinion (ω_p) can be calculated using equation (5).

$$\omega_p = \frac{229,2^0}{0,2 \text{ sec}} = \frac{1146^0}{\text{sec}} = 3,18 \text{ rotation/sec} \quad (5)$$

Based on calculation shown in equation (5) the planetary gear chosen for mechanism as shown in Fig. 2 have to be able to increase the flywheel rotation in accordance with the rotation requirements for the electric generator (50 Hz). The kinematics and

velocity diagram on the planetary gear pairs is shown

in Fig. 3.

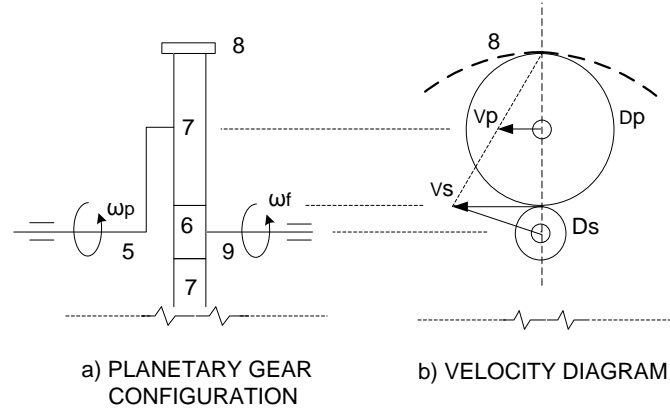


Figure 3. Kinematics and velocity diagram of planetary gear.

If the diameter of the planetary gear and the sun gear are D_p and D_s respectively, the length of the planetary (R) gear arm is $(D_p + D_s) / 2$. So that the tangential velocity of the planetary gear shaft (V_p), can be calculated using equation (6).

$$V_p = \omega_p (D_p + D_s) / 2 \quad (6)$$

From Figure 3b, it can be determined that the tangential velocity of the sun gear shaft is 2 times faster than the tangential speed of the planetary gear shaft. Because the rotating speed of the sun gear shaft is equal to the rotating speed of the fly wheel (see Fig. 2), it can be calculated by equation (7).

$$\omega_f = \frac{2\omega_p (D_p + D_s)}{D_s} \quad (7)$$

By designing D_p equal to $1.4 D_s$, then from equation (7) and equation (5), the value of ω_f can be obtained that is $\omega_f = 4.8$ $\omega_p = 4.8 \times 3.18$ rotation/second = 15.26 rotation/second. To be able to achieve the rotation required by electric generator (50 Hz), the mechanical system is used two pairs of planetary gear arrangements with the same geometry as the first one.

2.2 Electrical system

The electrical system utilizes the fly wheel rotation to rotate the electric generator. The electric generator is equipped with a diode rectifier to produce DC voltage and an ICs regulator to control the amount of current and voltage generated [9]. The diagram of the electrical system of the mechanical energy harvesting system is shown in Fig. 4.

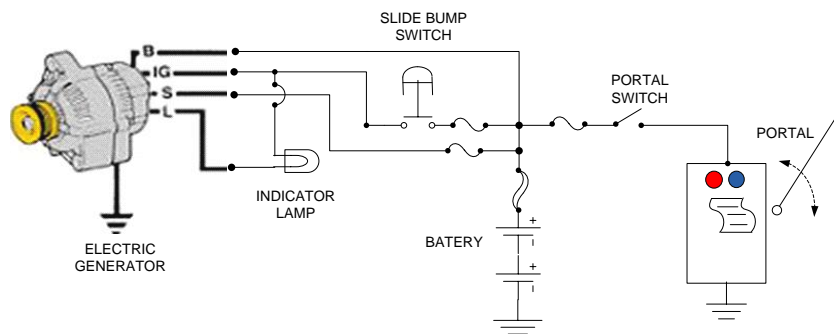


Figure 4. The electrical system diagram.

The electric generator has 4 terminals. The B terminal is one for supplying electrical energy produced by the electric generator to the battery. The S terminal is connected to the battery to monitor battery voltage and is used to control the electricity generation system of the electric generator. While the L terminal is used

for light indicator. The load of the electrical system consists of equipment for parking tickets printing and opening/closing of the portal. The process of printing and opening of the portal is activated manually by the driver when enter the entrance gate. The process of closing the portal is done automatically using the

input signal from the sensor, when the vehicle passes through the portal.

3. Results and discussions.

The results presented are the efficient portal design (low net energy needed to open/close the portal) and the capability of mechanical energy harvesting system to provide energy to operate the portal and parking ticket printer.

3.1 Energy for opening/closing the portal

The portal mechanical system consists of a portal (crossbar), a portal drive motor and a power transfer system. The portal is opened and closed by rotating the

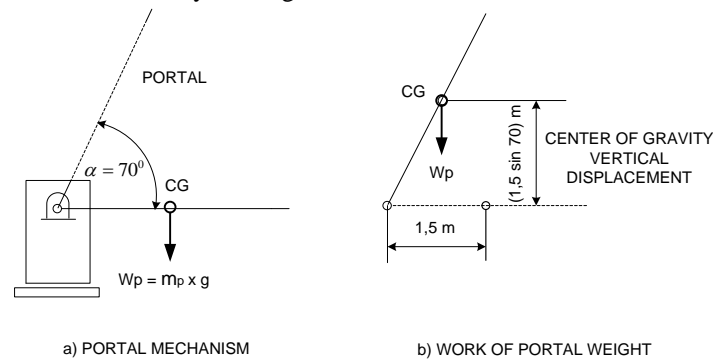


Figure 5. Dynamics of portal opening/closing system.

The portal is designed with maximum opening angles of up to 70° . In accordance with Fig. 5, the net energy, U_p needed to open the portal can be calculated by equation (8).

$$U_p = m_p g s_p \quad (8)$$

Mass of portal, m is 8 kg, acceleration of gravity, g is 9.8 m/sec^2 and s_p is vertical displacement of the portal's center of gravity. With the designed period and opening of the portal, and assuming that the energy to open and close the portal is the same, the total amount of energy needed to open and close the portal can be calculated as follows.

$$U_{p \text{ tot}} = 2 \times 8 \text{ kg} \times 9.8 \frac{\text{m}}{\text{sec}^2} \times 1.5 \text{ m} \sin 70$$

portal hinge at one end. The portal or crossbar is made from light weight material such as aluminum profiles, so that the power needed to open and close the portal is small. The portal has a length of 3m [8], and its weight is no more than 8Kg. For this light weight portal, the DC motor is selected as a driver. The power transfer system is used to adjust the output speed and torque, which is needed to move the portal. With the same amount of power, the output torque can be increased proportionally with decreasing output speed. Energy requirements for the mechanical system, can be analyzed from the dynamic of the portal opening/closing system as shown in Fig. 5.

$$U_{p \text{ tot}} = 221 \text{ Nm}$$

3.2 Energy obtained from the energy harvesting system.

Each time the vehicle pass the portal (barrier gate system) the vehicle will push sliding bump two times, first by the front wheels and second by rear wheels respectively. Each wheels will give an energy that is proportional to the weight of the vehicle. Therefore, the total energy of both front and rear wheels can be calculated using equation (1) by choosing the value of vehicle weight, W_k , equal to the total weight of the vehicle. Data of vehicle weight to determine the minimum energy from the lightest vehicle for this design is taken from the city car specification data as shown in Tabel 1.

Tabel 1. Specification of the light weight vehicle *

No	Brand name and model of vehicle	Engine capacity (cc)	Production year	Vehicle net weight (Kg)
1	Toyota Yaris 1.5 S M/T	1500	2013	1075
2	Suzuki Swift 1.5 GT 3	1490	2013	1080
3	Honda Jazz 1.5 RS	1497	2012	1090
4	Ford Fiesta Hatchback 1.4	1388	2012	1106
5	Nissan March 1.2	1198	2012	945
6	Suzuki Karimun Estilo 1.0	996	2012	850

* Taken from vehicle leaflet

Using data taken from the lightest vehicle (Suzuki Karimun), and assuming the driver's weight is 50 Kg, then the energy obtained from the total vehicle weight (900 Kg) that passing the portal can be calculated by using equation (1) as follows:

$$U_k = 900 \text{ Kg} \times 9,8 \frac{m}{sec^2} \times 0,12 \text{ m}$$

$$U_k = 1058 \text{ Nm}$$

The energy obtained from the lightest vehicle provides much more energy needed by the portal gate system.

The real performance of the mechanical energy harvesting system will be known after the field testing of the system.

4. Conclusion

Choosing the mechanical efficiency and electrical efficiency of the mechanical energy harvesting system for 0.7 and 0.8 respectively, the net energy obtained is $0.7 \times 0.8 \times 1058 \text{ Nm} = 592 \text{ Nm}$. This value is more than twice greater than the net energy needed to open and close the portal, which is 221 Nm. For this reason, it can be concluded that the design of this mechanical energy harvesting system is capable to provide the power needed to operate the portal (barrier gate) and the parking ticket printing.

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